

LRFD vs. KBDC for the design of Incheon Bridge



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Abstract: *The market of long span bridge construction has been increased in Korea, and as a result, the outstanding and rapid evolution of bridge technology has been observed. Tendency is also to apply more rationally the current design codes through mixed application of Korean and foreign design specifications. By comparison of design codes in tender design of Incheon Bridge which was determined to be designed in accordance with AASHTO LRFD, the possibility of lack in understanding of AASHTO LRFD was removed and the discrepancies due to flaws in Tender Design were planned to be adjusted in Detailed Design to satisfy relative requirements of safety. Also, another outcome of importance is the momentum of establishment of reliability-based code and standards in accordance with the international codes.*

Keywords: *LRFD, KBDC (Korean Bridge Design Code), bearing capacity of pile, Incheon Bridge*

1. INTRODUCTION

1.1 General

The Incheon 2nd Bridge Project does provide an expressway standard link across Incheon Harbour spanning from Songdo New Town area to Yongjong Island at a point Northeast of the IIA access roads. The East Connection (Incheon Side) will connect the Project to #2 Kyung-In Expressway, the future Incheon Main Arterial Road and the existing Coastal Ring Road. The West Connection (Island Side) will connect the Project to the IIA Expressway and the new Yongjong Arterial Road proposed, which is to be constructed by Incheon City.

The bridge and approaches support three lanes of traffic in each direction. The cross section components of the bridge conform to the “Standard Specifications of Road Structure Facilities (2002)” as published by MoCT, Republic of Korea.

The bridge structures have been composed of three structure types:

- The main, high level cable-stayed bridge (800m main span, 340m side spans, total length 1,480 m)
- Approach bridges rising up to the cable-stayed bridge; and
- Viaduct spans which extend at low level from each shore to the approach bridges.

The project was procured by the Korea Expressway Corporation on a BOT basis. As a fast track project, the design was prepared using AASHTO LRFD as a sequence of packages in accordance with the demands of the construction schedule. Based on the illustrative design, each of two consortiums prepared different tender design which has 700m main span length.

As per Client’s requirement, the main, cable stayed bridge have been enlarged to have 800m main span. The extensive scale for cable stayed bridge is conducted to receive the request that the width of navigation channel should be increased to give more safe access of Incheon Harbour. And the main span

of approach bridges are changed from 150m to 145m. So the tender design is revised. Followings are the brief history of the project.

- 1992. 6 : International Airport preliminary plan with sea crossing by tunnel or bridge
- 1999. 7 : AGRA(merged to AMEC) expressed an economic cooperation with Korea
- 2003. 6 : Conclusion of BTO Execution contract with KODA(concessionaire, SPC)
- 2004. 5 : Bidding and award to Samsung JV
- 2004.12: Change of main span length from 700m to 800m
- 2005. 6 : Agreement on construction execution plan and commencement

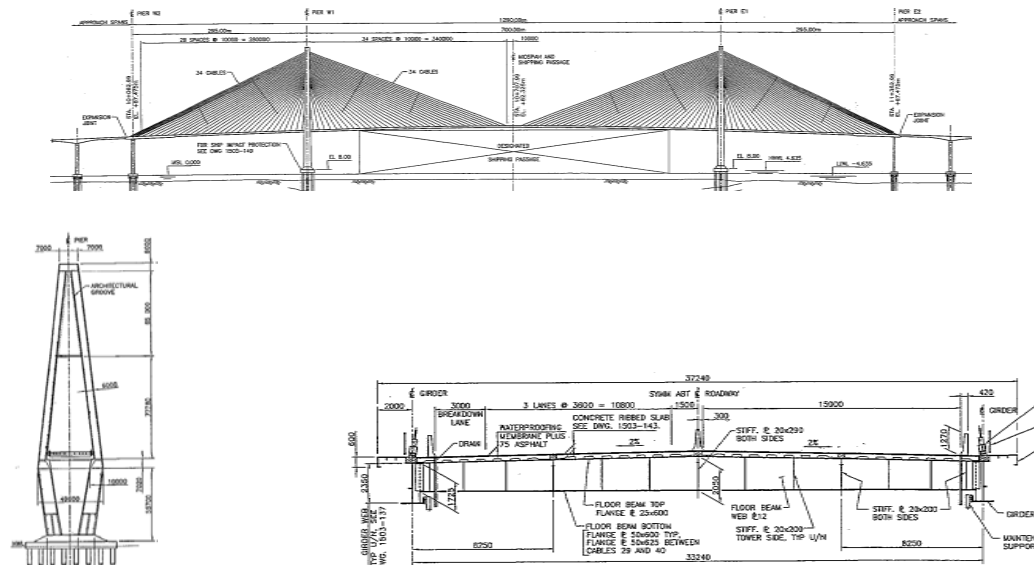
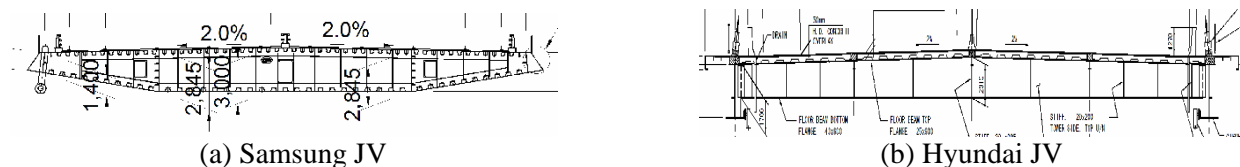


Figure 1: Illustrative Design by B&T in Canada



(a) Samsung JV

(b) Hyundai JV

Figure 2: Suggested cross section of superstructure (Tender Design)

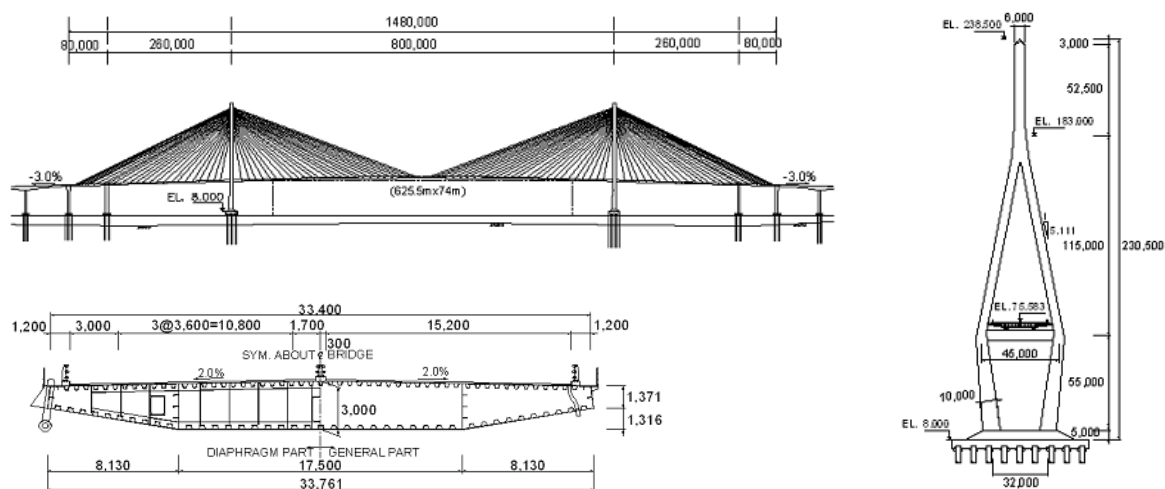


Figure 3: Final Design with 800m main span length

2. Design Check against LRFD

2.1 Background for Tender Design Check

In spite of being well experienced for long span bridges in Korea, Korean Bridge Design Code (KBDC) was not recognized to abroad as a proper code to Incheon Bridge. The KODA strongly urged that AASHTO LRFD should be adopted as a fundamental code. In addition, Project Performance Requirement(PPR) and Concessionaire Supplementary Requirements (CSR) was also required to be observed.

Government decided that the contractor carry out independent design check for the tender design before commencing of Detailed Design in order to remove any mistakes in application of LRFD.

According to PPR and CSR, an independent design check was carried out on the tender basic design 30days after the Conditional Letter of Award by an international bridge specialist selected by the Contractor and approved by the Concessionaire.

At the same time the Contractor engaged an independent Korean Bridge specialist, approved by the Concessionaire, who in conjunction with the international bridge specialist reviewed the tender basic design according to the KBDC and compared with AASHTO LRFD. The design check and code comparison were submitted to the Concessionaire. The Revised Tender Design Check will follow the same procedure with tender basic design check. Design check will be done for the main cable stayed bridge and approach bridge.

Independent check on the Tender Design of the Incheon 2nd Bridge were commissioned to both overseas and domestic design companies. Ove Arup & Partner International Ltd, the overseas specialist was instructed to conduct the inspection in compliance with AASHTO LRFD Bridge Design Specifications. Meanwhile, DM / BnSE JV, a domestic specialist, was requested to carry out the check based on the KBDC. Followings are the specific items requested to the above-mentioned consultancies to look into.

- Review on Tender Design with the 700m main span(Tender Design Check, TDC)
- Review on Tender Design with the changed main span to 800m (Revised Tender Design Check, RTDC)

The outcome of the independent check is stated in Tender Design Check Report and Revised Tender Design Check Report. And those reports mainly comprise the summarized discrepancies found between the requirements of KBDC and AASHTO LRFD Bridge Design Specifications.

The independent check over the Tender Design with revised main span of 800m was conducted only for the Approach Bridge and the Cable-stayed Bridge.

Consequently, the independent check results of the Tender Design with 700m main span were considered for the Viaduct.

2.2 Definition of Work Scope

The main roles for Independent Design Checker are to review the revised tender design according to the KBDC and to compare the result conjunction with the international bridge specialist who will review the design by AASHTO LRFD.

Under these requirements, DM & BnSE carry out Tender Design Check by KBDC for the following main structures;

- Cable Stayed Bridge
- Approach Bridge

In this work scope, Tender Design Check for the following structures is excluded;

- Ship Impact Protection
- Scour Protection
- Toll Plaza
- Temporary Works
- Any other structures except structures related to bridges

Wind loads are only considered as static wind pressure. So wind load test and buffeting analysis are excluded in work scope.

Tender Design Check is based upon the information as provided by the Tender Drawings. Any missing information has been assumed by Checker as per conventional engineering practice.

2.3 Design Criteria

1) Standard for Tender Design

The tender design of the Incheon 2nd Bridge are carried out in accordance with AASHTO LRFD Bridge Design Specifications, SI Units, Second Edition, 1998, (published by the American Association of State Highway and Transportation Officials, Washington DC) as revised by 1999, 2000, 2001, 2002 and 2003 Interim Revisions.

Additional Loads and load combinations are considered in addition to the loads and load combinations specified in AASHTO LRFD. In tender design of the project, these Additional Loads and load combinations was considered and treated in the same manner as loads and load combinations specified in AASHTO LRFD. Design will satisfy the strength and serviceability requirements of AASHTO LRFD for loadings which are the greater of:

The loads and load combination requirements of AASHTO LRFD, or The additional Loads and load combinations specified in Section 2.6.3 of PPR

2) Standard for Tender Check

The tender design check by DM and BnSE as Korean bridge specialist has been carried out based on KBDC, as defined in PPR 2.5.2, CSR 11.1. Auxiliary code & loads for tender check has been referred in a proper manner if required. The major applied loads and referred specifications in tender design and tender check are compared in table 1.

Table 1: Applied load and specifications

Item	Design	Check	Remarks
1. Dead Load	Additional Load for Details - Steel Deck 37% - Stay Cable 10%	Same as Design	Design data is used.
2. Live Load	LRFD & Additional Loads in PPR	KBDC	
3. Wind Load	Deck Transverse	LRFD	KBDC
	Deck Longitudinal	LRFD	BS5400
	Deck Vertical	LRFD	BS5400
	Tower	LRFD & Additional Loads in PPR	KBDC
	Cable	Additional Loads in PPR	KBDC
4. Breaking Load	LRFD	KBDC	
5. Snow	PPR	PPR	Local Condition Data
6. Temperature	LRFD & Additional Loads in PPR	KBDC	
7. Settlement	LRFD	KBDC	
8. Stream Pressure	LRFD & Additional Loads in PPR	KBDC	
9. Wave Load	PPR	PPR	
10. Earthquake	LRFD & Additional Loads in PPR	KBDC	
11. Cable Rupture & Replacement	PPR & PTI LRFD(2000)	PTI ASD (1993)	PTI Recommendation for Allowable Stress Design
12. Vessel Collision	AASHTO Guide Spec.	Not Applied	Dolphin is not reviewed.
13. Fatigue		KBDC	
LOAD COMBINATION	LRFD & Additional Loads in PPR	KBDC	

3. Summary of Check Results

3.1 Executive Summary

DM & BnSE have performed an independent analysis for checking of the Revised Tender Design of Incheon 2nd Bridge Project. They have performed a global analysis of final stages of the bridge structures primarily. Some erection stages of the bridges have been reviewed if required. Erection stages for cable stayed bridge have not been considered, because the safety of cable stayed bridges in erection stages is mainly dependent of wind stabilities. Without buffeting analysis and wind load test, it is not reasonable to assess an accurate evaluation on structural integrity during critical erection stage.

KBDC reads that the allowable-stress design should be employed for steel structures, and the strength design for concrete structures, respectively. On the contrary, AASHTO LRFD says that load and resistance factor design should be applied.

In some case, strict adoption of KBDC gives too conservative result. So designers generally refer other codes which are more reasonable for special figures. In this report, the KBDC is strictly adopted in most cases.

3.2 Cable stayed bridge

Superstructure

- From longitudinal analysis, the stress and stability for combined check of axial force and bending moment are satisfied.
- Fatigue stress is under the allowable fatigue stress range as specified in KBDC.
- From the buckling analysis, superstructure has enough stability.
- Deflection of mid span does not exceed the allowable deflection specification of KBDC.
- From the orthotropic deck plate design, floor rib and longitudinal rib are within the allowable stress.
- Cable stability is conformed by allowable stress design.
- From the eigenvalue analysis, dynamic behaviour is somewhat different between the TDC and RTDC.

Substructure (Pylon)

- Pylon section has a sufficient flexural, shear and torsional strength.
- Stress of crossbeam is over the allowable stress as specified in KBDC.
- Pile has a sufficient flexural and shear strength.
- Pile has sufficient bearing capacity in related with KBDC.
- Lateral deformation of pile at the ground level does not exceed the allowable range.
- Pile cap has a sufficient flexural strength but does not sufficient shear strength in some part.

Substructure (Anchor pier)

- Pier section has a sufficient flexural, shear strength.
- Pile has a sufficient flexural and shear strength.
- Pile does not have sufficient bearing capacity in related with KBDC (only at W3).
- Lateral deformation of pile at the ground level does not exceed the allowable range.
- Pile cap has a sufficient flexural strength but does not have sufficient shear strength in some part.

Substructure (Supplemental pier)

- Pier section has a sufficient flexural, shear strength.
- Pile has a sufficient flexural and shear strength.
- Pile does not have sufficient bearing capacity in related with KBDC.
- Lateral deformation of pile at the ground level exceeds the allowable range.
- Pile cap has a sufficient flexural strength but does not have sufficient shear strength in some part.

3.3 Approach Bridge

Superstructure

- From longitudinal analysis, stress development during erection is acceptable.
- Stress development at most of mid spans except end spans under serviceable condition is beyond allowable stress as specified in KBDC.
- Section has a sufficient flexural, shear and torsion strength.
- From transverse analysis, stress development under serviceable condition is acceptable.
- Transverse box section has a sufficient flexural and shear strength.
- Prestressing in rigid connection is sufficient to transmit axial force and moment.

Substructure

- Pier section has **not** sufficient flexural strength.
- Pile has a sufficient flexural and shear strength.
- Bearing capacity of all piles has a sufficient capacity.
- Pile cap has a sufficient flexural and shear (beam and punching) strength.

3.4 Summaries of design check

The check outcome of structural and geotechnical parts can be summarized as below.

■ Review results of structural part

Except for the loads and load combinations defined in AASHTO LRFD, most design results, which were obtained by reviewing the methodology stated in AASHTO LRFD and considering additional loads and load combinations stipulated in PPR, proved corresponding with KBDC.

However, several discrepancies were found based on difference in design concept or due to some errors caused in the process of making Tender Design. Considering the discrepancies caused by different design concept, additional changes was not made to the Detailed Design within the range where given requirements are satisfied.

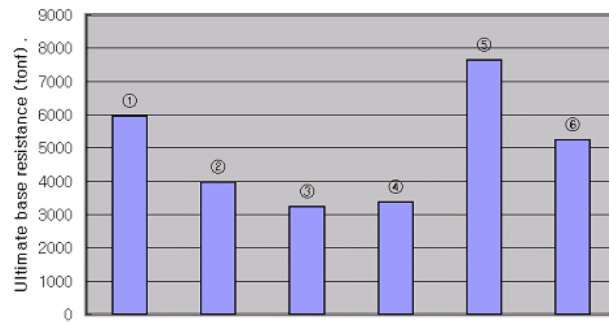
On the contrary, the discrepancies due to flaws in Tender Design were planned to be adjusted in Detailed Design to satisfy relative requirements of safety.

■ Review results of geotechnical part

Some discrepancies were spotted concerning bearing capacity of piles, however, those are based on the difference in design concept between domestic allowable stress design method and AASHTO LRFD. In the mean time, in Detailed Design, the final results of geotechnical investigation and pile load test was reflected so as to meet the design standards of AASHTO LRFD.

Table 2: Comparison of base resistance formula

Spec	Base Resistance Formula	Remark	No
• KGDBC, 2003	$q_p = 5 \sim 8q_u, (q_u = q_u / 5)$	• Teng(1962) • Used UCS	①
	$q_p = 4.5q_u \leq 10\text{MPa}$	• ARIGEMA(1992) • Used UCS	②
	$q_p = 2.7q_u, (q_u = q_u / 5)$	• Rowe and Armitage(1987) • Used UCS	③
• AASHTO(LRFD) • FHWA-IF-99-025 • Canadian Foundation E. M. • KGDBC, 2003	$q_p = 3q_u \cdot K_{sp} \cdot d$ $K_{sp} = \frac{3 + s_d / D}{10\sqrt{1 + 300t_d / s_d}}$ $d = 1 + 0.4 \frac{H_z}{D_z} \leq 3.4$	• Ladanyi • Used UCS & joint spacing • Considering rock embedded depth	④
• FHWA IF-99-025 • KGDBC, 2003	$q_{max} (\text{MPa}) = 4.83[q_u (\text{MPa})]^{0.51}$	• Zhang and Einstein(1998) • Used UCS • Applied by B&T(Canada) in illustrative design	⑤
• "Introduction to Rock Mechanics"	$q_{max} = q_{u(\text{design})} (N_\phi + 1)$ $N_\phi = \tan^2 (45 + \phi / 2)$ $q_{u(\text{design})} = q_u / 5$	• R. E. Goodman(1980) • Used UCS • Used friction angle of rock	⑥



Above graph is the base resistance calculation result in case of 2.4m pile diameter and 5m penetrated in soft rock.

- Condition: diameter=2.4m, uniaxial compression strength of soft rock=15mpa, socket depth=5m, RQD of soft rock=50%, class=granite

In the case of embedded pile on weathered to soft rock, the tip resistance should be conserved as indicated in KBDC (substructure 2001), AASHTO standard (1996), since the strength of the soft rock is little, regardless of the RQD. As a result, applied formula in tender design was Ladanyi formula-④ that citation from many specifications (AASHTO LRFD, FHWA, CFEM, KGBDC etc.) in base resistance estimation, because of the formula is not overestimate resistance and considering rock embedded depth. And, other resistance formula selection procedure was not necessary in detail design step, because of load test (O-Cell Test) result was applied in detail design.

4. CONCLUDING REMARKS

This paper presented the comparison of design codes in case of the Incheon Bridge tender design. As shown in this, the establishment of reliability-based code and standards in accordance with the international codes is found to be very important in the view point of competitiveness in world market. Fortunately, the standards have been developed and verified using the database and experience gathered since 30 years. The technical achievements of the Korean bridge engineering community and ambitious R&D program launched in a context of unprecedented bridge construction project will make it.

REFERENCES

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